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(54) Locking mechanism for the crankshaft of an internal combustion engine

(57) A locking mechanism (6) is provided to block the internal combustion engine (1) at prepositioned cranking angle after shutting down. Preferably, the crankshaft of the engine is positioned at a crankshaft angle that is favorable for cranking. Prepositioning of the crankshaft angle namely results in a lower first compression torque and therefore increases kinetic energy stored in the crankshaft lumped inertia. The required maximum torque of the cranking aid (2a, 2b, 2c) can therefore be reduced.

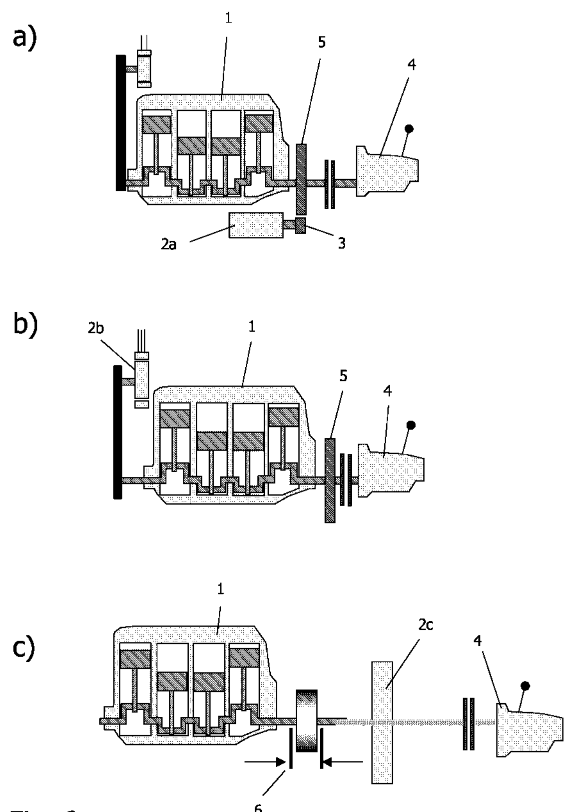

Fig. 6

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Description

[0001] The invention relates to a locking mechanism for the crankshaft of an internal combustion engine, an internal combustion engine that comprises such a locking mechanism, and a method of controlledly shutting down and restarting an internal combustion engine, wherein the internal combustion engine is stopped in a predetermined rest condition.

[0002] A method and a device for the controlled shutting down and restarting of an internal combustion engine are described in WO 01/48373 A1. According to that document the engine is actively or passively positioned at a predetermined cran king angle at rest which is stored and later available at restart. The predetermined resting angle is then used to initiate cylinder-specific fuel injection and ignition.

[0003] In order to start an internal combustion engine, some starter must accelerate the crankshaft to a given minimum rotational speed. The motoring torque that the starter encounters has a reciprocating component that is dependent on crankshaft angle and is largely caused by the compression and decompression of gas in the cylinders. The reciprocating component results in peaks of the motoring torque that must be overcome by the torque delivered by the starter and the inertial energy stored in the combination of starter and crankshaft.

[0004] Moreover, the total motoring torque increases as the temperature decreases. Thus it is necessary to implement a starter with enough low-speed torque to overcome the torque peaks at low temperatures. At warmer temperatures, a smaller electric machine would be sufficient, but it is necessary to install a larger, overdimensioned machine to cover the entire range of operating temperatures encountered by a vehicle. If the size of the electric machine for cold weather starts could be reduced, a smaller and cheaper electric machine could be implemented.

[0005] It is an object of the present invention to provide means that assist the exploitation of a defined resting angle of the crankshaft of on internal combustion engine for different purposes, especially for an improved restarting of the engine.

[0006] This object is achieved by a locking mechanism according to claim 1, an internal combustion engine according to claim 7, and a method according to claim 8.

[0007] Preferred embodiments of the invention are subject of the dependent claims.

[0008] According to a first aspect of the invention, a locking mechanism for the crankshaft of an internal combustion engine is provided which is able to block rotation of the crankshaft in one and/or two directions. Such a mechanism guarantees the maintenance of a certain crankshaft angle after shutting down of the internal combustion engine. Thus, the crankshaft angle is definitely available at restart of the engine, and elaborate methods to restart the engine may rely on it.

[0009] The locking mechanism may be realized in different ways. According to one embodiment, it may be realized as a freewheel clutch which allows rotation of the crankshaft in only one direction when it is engaged. Freewheel clutches are known e.g. from automatic transmissions and from starter motors. Preferably, the mentioned freewheel clutch is positioned between a gearbox and the internal combustion engine.

[0010] According to another aspect of the invention, the locking mechanism is designed such that it blocks rotation in two directions. Such a locking mechanism prevents in a vehicle with a manual transmission that a prepositioned crankshaft angle may be changed if the vehicle is shoved while it is parked and in gear.

[0011] The aforementioned locking mechanism may be realized by pins and/or ratchets that engage with a gear on the crankshaft. Alternatively, such a locking mechanism may be realized by a friction belt that engages with the crankshaft.

[0012] The invention comprises an internal combustion engine with a locking mechanism of the above mentioned kind. When activated, the locking mechanism blocks rotation of the crankshaft in one or in two directions. This prevents an undesirable and unnoticed change in the cranking angle between shutting down and restart of the engine.

[0013] Moreover, the invention comprises a method for controlledly shutting down and restarting an internal combustion engine, wherein the internal combustion engine is stopped in a predetermined rest condition and upon restarting is started against a reciprocating torque. The method is characterised in that the predetermined rest condition is so selected that the torque is decreasing during the first phase in the starting procedure, and that the crankshaft of the internal combustion engine is blocked with a locking mechanism of the kind described above in the predetermined rest condition.

[0014] By prepositioning the engine in a condition with initially decreasing motoring torque, a high amount of inertial energy can be stored in the spinning starter and crankshaft before the first compression torque peak is reached. Thus, the peak can be overcome with less torque of the starter, i.e. the torque rating of the electric machine can be reduced. This allows the use of a smaller starter while guaranteeing at the same time a reliable function even at low temperatures where high motoring torques are needed. In order to prevent changes in crank angle due to a pressure in the cylinders of the internal combustion engine or due to a movement of the parked vehicle while it is in gear, the crankshaft of the engine is locked with the locking mechanism in the rest condition.

[0015] Preferably, the predetermined rest condition of the internal combustion engine is chosen such that the average motoring torque is at or just beyond its minimum in this state. In this way a maximal amount of kinetic energy can be stored in the system by the starter before the following peak of motoring torque is reached.

[0016] The engine is preferably positioned in the predetermined rest condition just after it has been shut down in order to take advantage of the lower motoring friction associated with warm operating temperatures. In this case the prepositioning of the engine can be done by a starter which would be too weak for this movement in a cold state of the engine.

[0017] Particularly for the aforementioned movement of the engine it is necessary to verify that the predetermined rest condition is reached. To this end the torque and/or the cranking angle may be measured, especially during the positioning of the engine.

[0018] In principle the described method is useful for every kind of starter that may be used for cranking an internal combustion engine. However, it is particularly advantageous if an Integrated Starter Generator (ISG) is used for cranking. Such an Integrated Starter Generator can be operated like a starter motor that transforms electrical energy into mechanical energy or vice versa as a generator that produces electricity from mechanical movement. Integrated Starter Generators are typically coupled to the crankshaft with a rather low transmission ratio in comparison to normal starters. Therefore they have to be designed rather powerful in order to produce the required torques. For this reason, ISGs do particularly profit from a reduction of the torque requirements. Moreover, they have a larger potential for storing kinetic energy due to their high inertial mass.

[0019] The invention comprises a control system for the controlled shutting down and restarting of an internal combustion engine, too. The system comprises means for shutting down an internal combustion engine in a predetermined rest condition. The control system is characterised in that the predetermined rest condition is so selected that the torque is decreasing during the first phase in the starting procedure. As already explained with respect to the aforementioned method, such a system allows for a lighter starter while at the same time guaranteeing a reliable cranking.

[0020] Due to its low transmission ratio and its high inertia, it is preferable if the starter is an Integrated Starter Generator.

[0021] Moreover, the control system may comprise a cranking angle sensor and/or a torque sensor. Such sensors allow a closed-loop control of the positioning of the internal combustion engine and a verification that a desired rest condition is reached. It should be noted that the cranking angle sensor should be capable to measure the cranking angle especially at low or zero speed.

[0022] Preferred embodiments of the invention will now be described with reference to the accompanying figures, in which

Fig. 1 shows a diagram of the engine speed vs. time during cranking;

Fig. 2 shows the engine friction torques vs. the ambient temperature;

Fig. 3 shows the torque required to get through the first compression vs. the initial cranking angle;

Fig. 4a-d show the relative cylinder pressure at different initial crank angles;

Fig. 5a-b show gas torque during the first compression in one cylinder and in the whole engine, respectively;

Fig. 6a-c show an internal combustion engine with a conventional starter, an ISG coupled via a belt, and an ISG directly coupled to the crankshaft, respectively;

[0023] The cranking process of an internal combustion engine is defined as motoring the engine by an external source (cranking device or starter like starter motor, Integrated Starter-Generator ISG, etc.) to a certain engine speed from which the engine can commence firing. Figure 1 is a diagram of the engine speed (vertical axis) versus time (horizontal axis) for a typical cranking process. This process is a motored process, where the torque needed to accelerate the engine is delivered by the cranking device.

[0024] During the cranking process, the cranking device should deliver a torque to:

a) Overcome the break-away torque: this is the static-friction torque of the engine.

b) Get through the first compression.

c) Reach a final motored engine speed at which the engine can successfully start firing. Namely, there is a minimum engine speed n_{min} from which combustion can take place in a stable manner.

d) Crank the engine in a specified time. Cranking should take place within a certain specified time t_c (dependent on customer perception and acceptance), that is dependent on temperature. At cold cranking temperatures, e.g. -29°C, the acceptable time will be much longer than at 20°C.

[0025] At lower temperatures friction increases due to higher oil viscosity and smaller clearances between adjacent moving engine parts. At lower temperatures both the break-away torque and the friction torque increase. In Figure 2, the measured break-away torque and average friction torque are displayed for a typical engine as function of temperature. This diagram clearly shows that the maximum torque the cranking aid should deliver is determined by the lowest temperature at which the engine still has to be cranked successfully. Cold cranking therefore determines the maximum torque the cranking device has to deliver.

[0026] The break-away torque is determined by the engine design and is the minimum value the cranking device should deliver. The torque needed to get through the first compression however can be influenced by changing the initial position of the crankshaft. Figure 3 depicts the torque needed to get through the first compression at a cold cranking temperature of -29°C for a typical engine in dependence on said initial cranking angle. Three different curves are shown corresponding to three different values J of the inertia moment of engine and starter. From Figure 3 it is evident that the torque required to get through the first compression has a minimum at a certain optimal crank angle (roughly between 45° to 80°). This is the result of a lower compression pressure in the first compressing cylinder. This lower pressure results in a lower compression torque and therefore the residual torque that the cranking aid has available (difference between what the cranking aid should deliver and the sum of friction and compression torque of engine) can be stored as kinetic energy in the lumped crankshaft inertia by accelerating it. This kinetic energy can be used in a later phase (i.e. during the maximum of the co m-pression torque) by extracting torque from the lumped crankshaft inertia through deceleration.

[0027] The effects of the initial crankshaft position on the maximum cylinder pressure and gas torque are displayed in Figures 4 and 5, respectively. Figure 4a to 4d show the relative cylinder pressure (vertical axis) of a 4 cylinder engine versus cranking angle (horizontal axis). The initial crank angle α_0 prior to cranking is -180° in Figure 4a, -135° in Figure 4b, -90° in Figure 4c, and -45° in Figure 4d whereby α_0 is 0° at TDC firing of cylinder 1. Comparison of the figures shows that the first peak of cylinder pressure is minimal at an initial cranking angle of -45°. Figures 5a and 5b are diagrams of the gas torque of a 4 cylinder engine during the first compressions (initial crank angle: -90°) showing the contribution of a first cylinder (Figure 5a) and the complete engine (Figure 5b).

[0028] The optimal positioning of the initial crank angle does not only lower the torque needed to get through the first compression (improves cranking success) but also influences the time needed to crank the engine. The lower first compression peak namely results in a faster engine acceleration which has implication with for instance Stop-Start (hot cranking).

[0029] Figures 6a to 6c depict three different types of starters for an internal combustion engine 1. Figure 6a shows an conventional starter motor 2a that is coupled to the crankshaft via a pinion 3 and a ring gear 5, the transmission ratio of ring gear to pinion being typically in the order of 14:1. Moreover, a clutch/gearbox 4 is shown. Figure 6b shows an Integrated Starter-Generator (ISG) 2b that is coupled via a belt to the internal combustion engine 1, the pulley ratio of this coupling being about 3:1. Moreover, a flywheel 5 and a clutch/gearbox 4 are shown. Finally, figure 6c depicts an ISG 2c that is integrated into the flywheel between internal combustion engine 1 and clutch/gearbox 4. The transmission ratio is 1:1 in this case.

[0030] Figure 6c shows a crankshaft lock 6, too. A crankshaft lock has the advantage of maintaining a prepositioned optimal crankshaft starting angle or any crankshaft angle that has been determined and stored before the engine is shut down. Pre-positioning is best done immediately before engine shutdown while it is still warm to minimize the required electrical energy. However, an angle near a torque peak is unstable, because the torque applied to the crankshaft by compressed gas may rotate the crankshaft out of the optimal position after the prepositioning is completed. Therefor, a mechanism is required that allows the crankshaft to be positioned by the starter and then to hold the preset angle against the forces of the compressed gasses. One possibility for such a mechanism is a freeway clutch, which only allows rotation in one direction when it is engaged. In the case of a vehide with a manual transmission and a freeway clutch, the prepositioned crankshaft angle may still be changed if the vehicle is shoved while it is parked and in gear. The mechanism 6 of figure 6c that locks the rotation of the crankshaft in both directions would prevent this.

[0031] Besides prepositioning the crankshaft, it is also desirable to determine and save the crankshaft angle that a combustion engine arrives at when it is shut down without actively influencing it. The stored crankshaft angle could then be used to shorten starting times, because it would not be necessary to rotate the crankshaft several times in order to initiate the determination of crankshaft position. In the current state of the art, the engine must be rotated a minimum number of times before a determination is possible. If the crankshaft angle at engine shutdown is stored for use when restarting, the crankshaft should also be locked to prevent rotation in both directions. The locking mechanism 6 of figure 6c accomplishes this, too. A locking mechanism 6 that prevents rotation in two directions may be realized by pins or ratchets that engage with a gear on the crankshaft or by a friction belt.

[0032] When starting a vehicle in cold weather, a starter-alternator 2b, 2c is at a disadvantage compared with a conventional starter 2a. In the case of a crankshaft mounted starter-alternator 2c, there is no torque multiplying gear or pulley ratio between the electric machine and crankshaft, and in the case of a belt driven starter-alternator 2b, the maximum ratio is dictated by packaging constraints and inertial effects of the electric machine on the drive train during acceleration of the vehicle. While a B-ISG 2b may have a maximum pulley ratio to the crankshaft of about 3:1, gear ratios of 14:1 are possible with a conventional starter motor 2a. The power rating and maximal torque of a starter-alternator must be large enough to overcome motoring torque peaks that are encountered when the combustion engine is cranked. As explained above, the peaks are associated with a reciprocating component of the motoring torque that is dependent on the crankshaft angle. The total motoring torque including the absolute value of the peaks increases as the temperatures decrease, and the starter-alternator must be dimensioned to overcome them at the lowest defined ambient operating temperature in order to start the engine. However, a vehicle encounters these very low operating temperatures seldom. For the ambient temperatures that a vehicle usually encounters, the motoring torque that a starter-alternator has to overcome is much lower than the extreme cold weather values. Hence, the electric machine is usually dimensioned at a much higher torque rating than is normally required. It is therefore desirable to lower the required torque during cold weather starting by maximizing the inertial energy stored in the rotating crankshaft and starter-alternator before the first compression is reached.

[0033] Engine motoring torque and friction are lower when the engine is warm, and so prepositioning is accomplished with a minimum in electrical energy immediately after the engine is shut down while it is still warm. The optimal position just after a torque peak could be determined either by actually sensing the crankshaft angle or determining the motoring torque as the crankshaft is being positioned. Sensing the crankshaft angle requires an angle position sensor that operates at low or zero rotational speed, and these may already be used for the control of starter-alternators with permanent-magnet synchronous (PSM) electric machines.

[0034] A further advantage in prepositioning the crankshaft is a lowering of the amount of rotations needed to restart a combustion engine. In the current state of the art, a minimum number of rotations are necessary for the Engine Control Module to observe signals coming from the crankshaft position sensor in order to ascertain the correct position. If the absolute crank angle is known in advance when the engine is started, fuel delivery and ignition could be initiated without first rotating the crankshaft to determine crank angle.

Claims

1. A locking mechanism for the crankshaft of an internal combustion engine which is able to block rotation of the crankshaft in one and/or two directions.

2. The locking mechanism of claim 1, **characterised in that** it is realized as a freewheel clutch which allows rotation of the crankshaft in only one direction when it is engaged.

3. The locking mechanism of claim 2, **characterised in that** the freewheel clutch is positioned between a gearbox and the internal combustion engine.

4. The locking mechanism of claim 1, **characterised in that** it blocks rotation in two directions when it is engaged.

5. The locking mechanism of claim 4, **characterised in that** it is realized by pins and/or ratchets that engage with a gear on the crankshaft.

6. The locking mechanism of claim 4, **characterised in that** it is realised by a friction belt that engages with the crankshaft.

7. Internal combustion engine (1), **characterised in that** a locking mechanism (6) according to one of claims 1 to 6 is coupled to its crankshaft.

8. Method of controlledly shutting down and restarting an internal combustion engine (1), wherein the internal combustion engine is stopped in a predetermined rest condition, **characterized in that** the crankshaft of the internal combustion engine is blocked with a locking mechanism according to one of claims 1 to 6 in the predetermined rest condition, and **in that** the predetermined rest condition is so selected that the torque is decreasing during the first phase in the starting procedure.

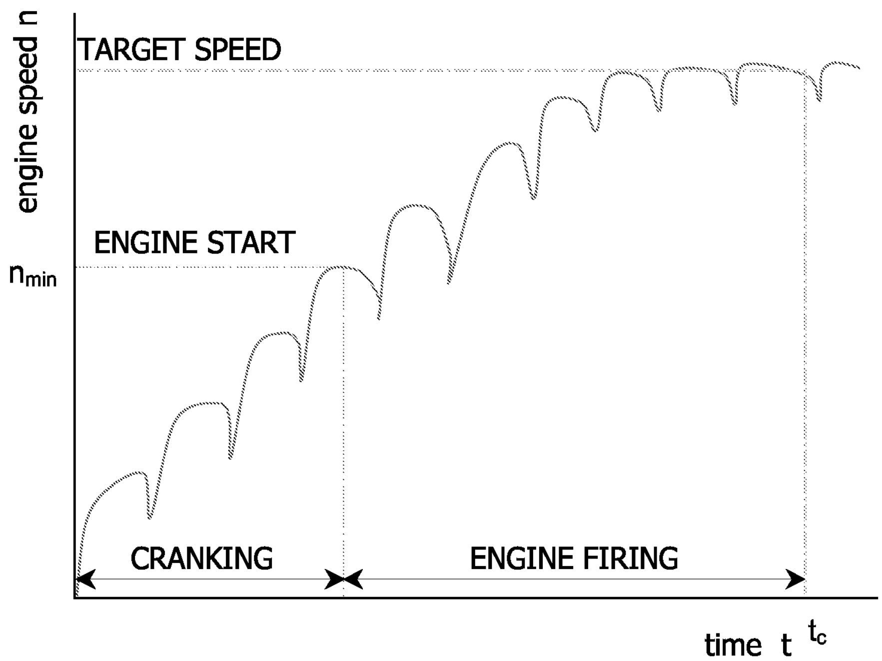

engine speed n
TARGET SPEED
ENGINE START
n_{min}
CRANKING
ENGINE FIRING
time t
t_c

Fig. 1

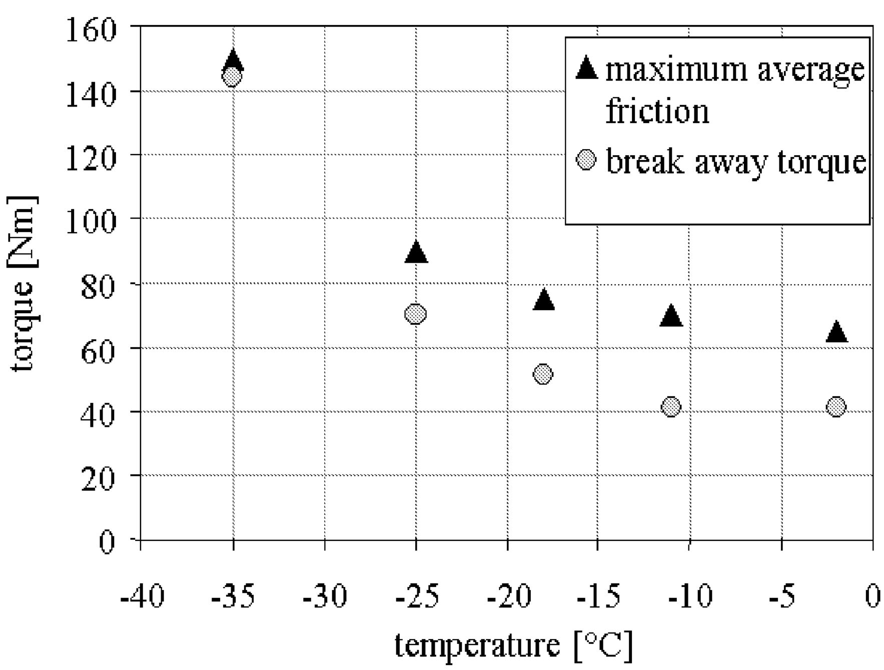

160
140
120
100
80
60
40
20
0
torque [Nm]
-40
-35
-30
-25
-20
-15
-10
-5
0
temperature [°C]
maximum average friction
break away torque

Fig. 2

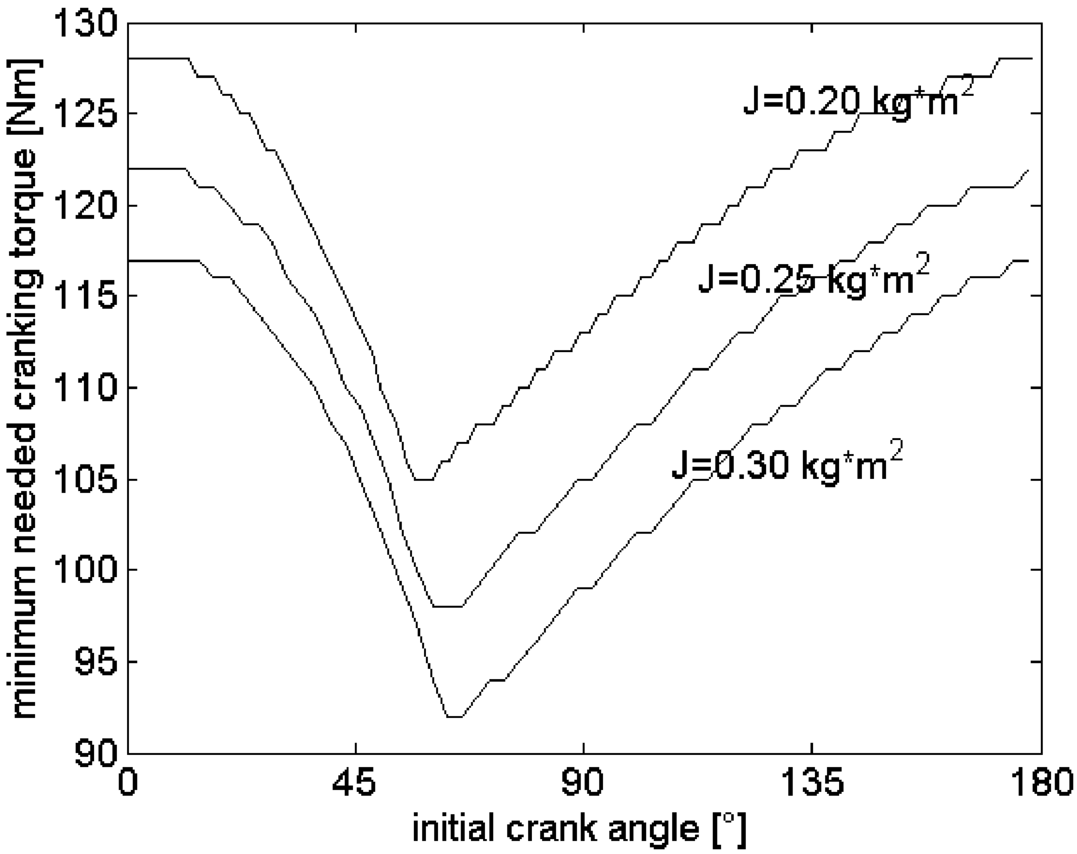

130
125
120
115
110
105
100
95
90
0
45
90
135
180
minimum needed cranking torque [Nm]
initial crank angle [°]
J=0.20 kg*m^2
J=0.25 kg*m^2
J=0.30 kg*m^2

Fig. 3

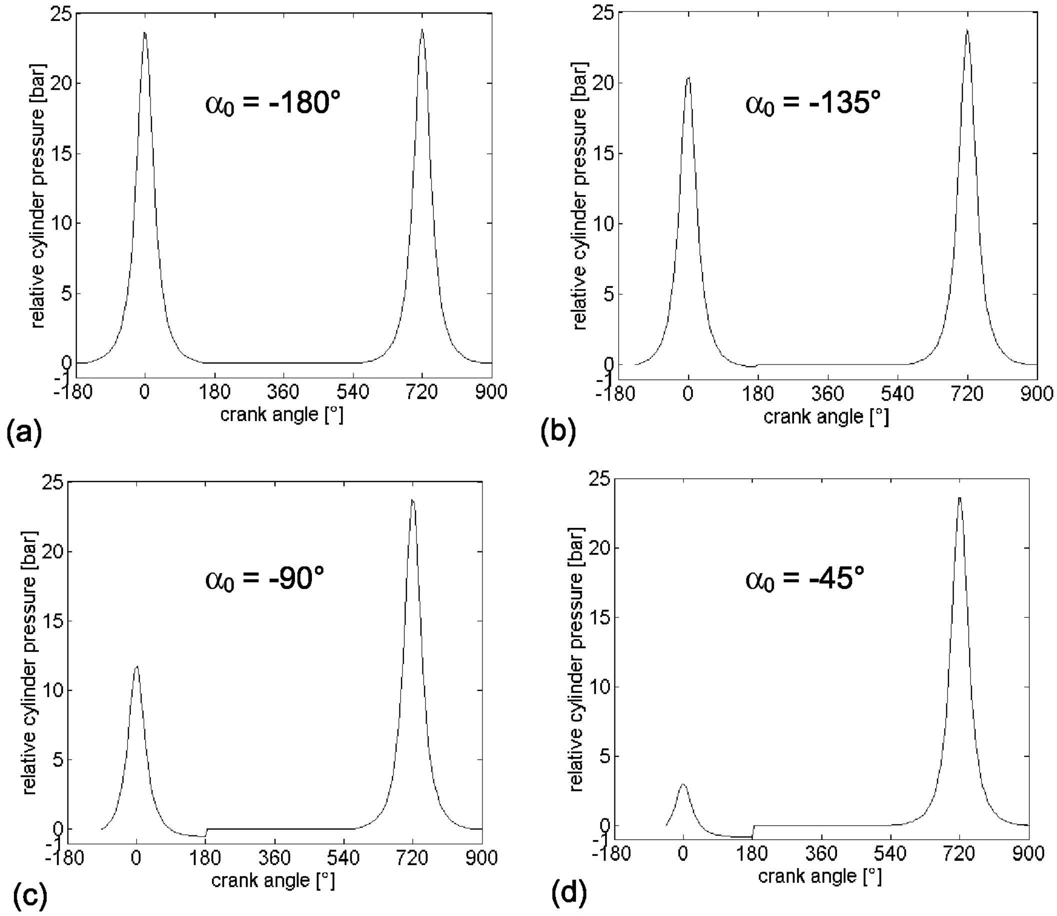

α_0 = -180°
α_0 = -135°
α_0 = -90°
α_0 = -45°
relative cylinder pressure [bar]
crank angle [°]
(a)
(b)
(c)
(d)

Fig. 4

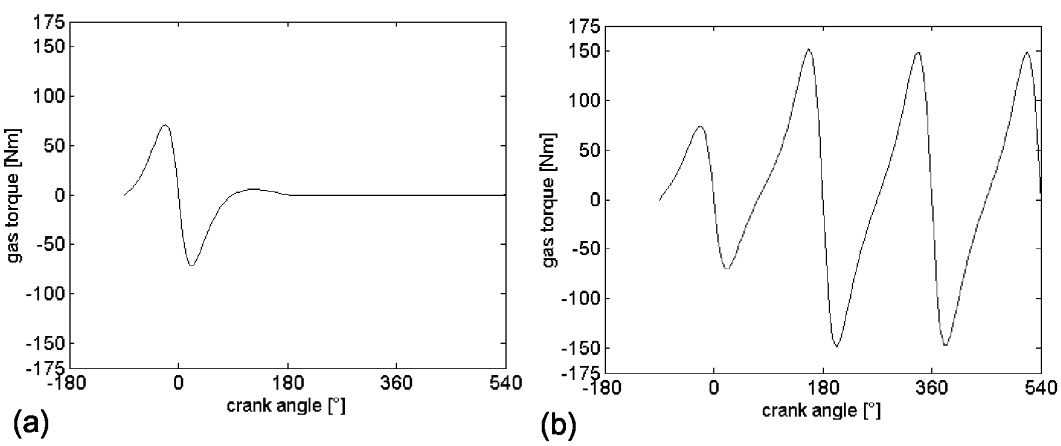
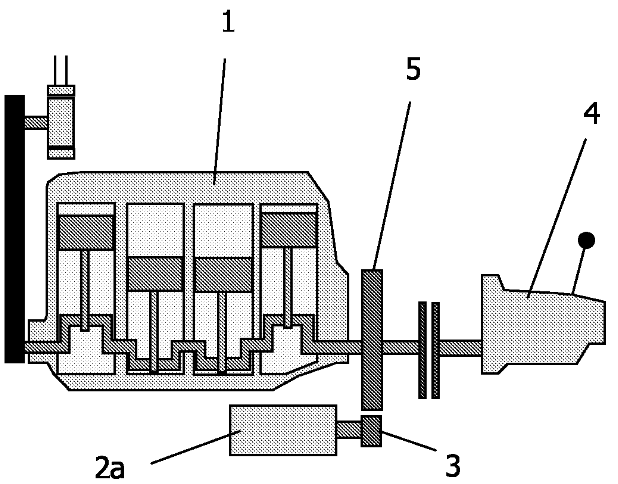
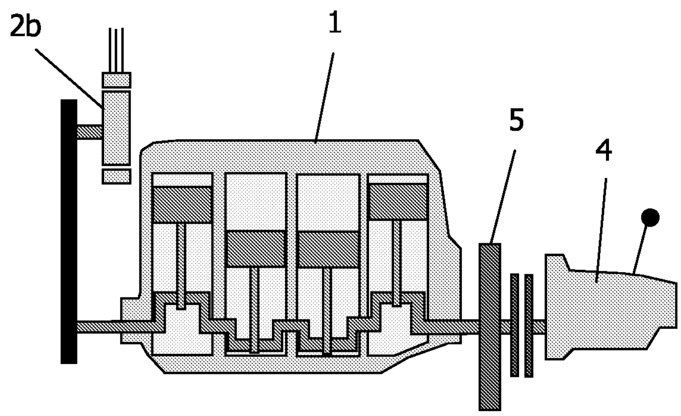

gas torque [Nm]
crank angle [°]
(a)
(b)

Fig. 5

a)



b)



c)

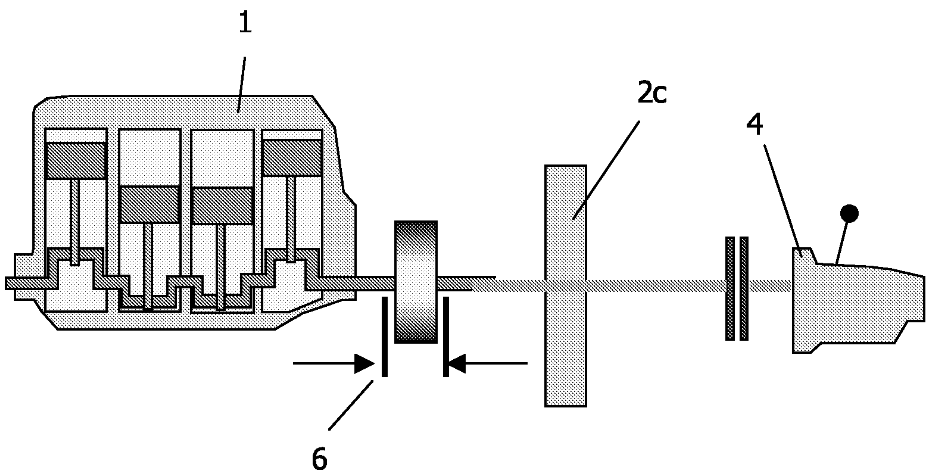


Fig. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 02 10 2630

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29 January 2003	Wassenaar, G

CATEGORY OF CITED DOCUMENTS

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